USING INTERACTIVE LECTURE DEMONSTRATIONS TO INVIGORATE CHEMISTRY LECTURES

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ABSTRACT

Demonstrations are commonly used in Chemistry lectures to illustrate chemical phenomena and as entertainment. Interactive lecture demonstrations have been introduced into first year undergraduate classes which more deliberately connect the demonstration with the course content. Through the development of worksheets, students are actively engaged with predicting, observing and explaining the results of the demonstration. Evaluation of this approach through surveys and class observation suggest that students found it engaging and effective for their learning.

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INTRODUCTION AND BACKGROUND

Demonstrations of chemical reactions and phenomena are widely used in undergraduate chemistry courses. They are incorporated in lectures for a number of reasons including:

- as an illustration of chemical concepts or phenomena,
- as a device to break up theoretical material, and
- as pure entertainment.

All of these reasons are valid and educationally defensible. Demonstrations provide the element of ‘live theatre’ that many students remember and report, via evaluations, to be valuable in their enjoyment of the course (Meyer, Panee, Schmidt, & Nozawa, 2003, Tanis, 1984).

Developing new demonstrations requires considerable effort, much of which is focussed on the requirement for the demonstration to be safe to perform in front of a large class. Lecturers thus often cultivate their own suite of preferred demonstrations, perhaps sourced from peers or from rich resources such as the American Chemical Society and Royal Society of Chemistry compilations. These resources include details of procedures, required equipment and chemicals, safety and disposal information and even teaching ideas. Even so, performing demonstrations is a considerable investment. It requires equipment and chemicals to be purchased and maintained and time to be spent setting up and clearing away. For the lecturer, it requires valuable class time to be devoted to the demonstration itself and for its explanation. Roadruck (1993) has suggested that some teachers avoid demonstrations because they are time consuming to prepare and present, involve undue hazards and entertain rather than teach.

The lecturer traditionally performs chemical demonstrations on the front bench of the lecture theatre, perhaps now assisted by a video camera in large lecture theatres. There may be some interaction with the audience but the experience, whilst engaging, is still essentially didactic and centred on the teacher. In the innovation described here, we sought to embed demonstrations as a key and defining element within an active learning approach. By actively engaging students in the science being illustrated in each demonstration, we sought to *utilise* their entertainment value to deepen learning and to ensure the on-going relevance of face-to-face education. In doing so, we were anxious to avoid the pedagogical issues identified by Roadruck (1993) and purposefully “make conscious use of our understanding of how people learn to guide … the presentation of demonstrations”.
‘Interactive lecture demonstrations’ (ILDs) have been used in Physics for a number of years (Sokoloff & Thornton, 2004, Sharma, Johnston, Johnston, Varvell, Robertson, Hopkins, Stewart, Cooper, & Thornton, 2010). Large parts or even whole lectures are given over to individual experiments with a

cycle of students predicting, observing and then explaining the physical phenomena. Given the learning gains reported in Physics, we were interested in how well this model would transfer to chemistry, given the differences between the types of phenomena being demonstrated. Wood and Breyfogle (2006) have reported promising results on the use of ILDs in Chemistry. These authors used electronic keypads to record and address student misconceptions with evaluations suggesting a positive effect on engagement. Demonstrations in Chemistry tend to be over in a flash whereas those in Physics can involve multiple measurements, therefore a different approach seems to be needed'

Over recent years, the 'Active Learning in University Science' (ALIUS) group has been involved in a sustained effort to establish a new direction in learning and teaching in Chemistry (Bedgood, Yates, Buntine, Pyke, Lim, & Mocerino, 2008; Bedgood, Yates, Buntine, Pyke, Lim, Mocerino, Zadnik, Southam, Bridgeman, Gardiner, & Morris, 2010a, 2010b; Bedgood, Mocerino, Buntine, Southam, Zadnik, Pyke, Lim, Morris, Yates, Gardiner, & Bridgeman, 2010). Active learning techniques for large classes using worksheets are now fully integrated into lectures and tutorials in first and second year chemistry at the University of Sydney. These seek to guide students towards building their own understanding of concepts and ideas and evolve from the 'Process Orientated Guided Inquiry Learning' (POGIL) approach widely used in North America (Moog & Spencer, 2008) to suit the Australian context.

The worksheet approach (Bridgeman, 2012a, 2012b) is purposefully designed to promote students interacting with chemical structures and problems using a pen and paper approach. The worksheets are made available as hard copies to the students at the start of each lecture and were also made available online with short answers shortly after class. Each worksheet is designed to provide some background theory to support the lecture slides and to fit on 2 sides of A4 paper to minimise costs and help control the amount of content. The approach to ILDs that we report here was designed to extend but integrate into this model.

Our lectures now include an instructor-led review of the previous class with some review questions for students followed by interspersing of segments involving 10-12 minute mini-lectures, chemical demonstrations and 4-5 minute worksheet-based group tasks and feedback. Such variation and pacing seems to be optimal for keeping students engaged in class (Bunce, Flens, & Neiles, 2010, Bligh, 2000, McKeachie, 2002). By rotating delivery and activity throughout a 50-minute lecture students' attention can be maximised. The timeline, illustrated in Figure 1, is designed to introduce variation for learners and teacher whilst ensuring that both have a structure to work within. The ILD innovation described in this paper was designed to become an integral part of this sequence.

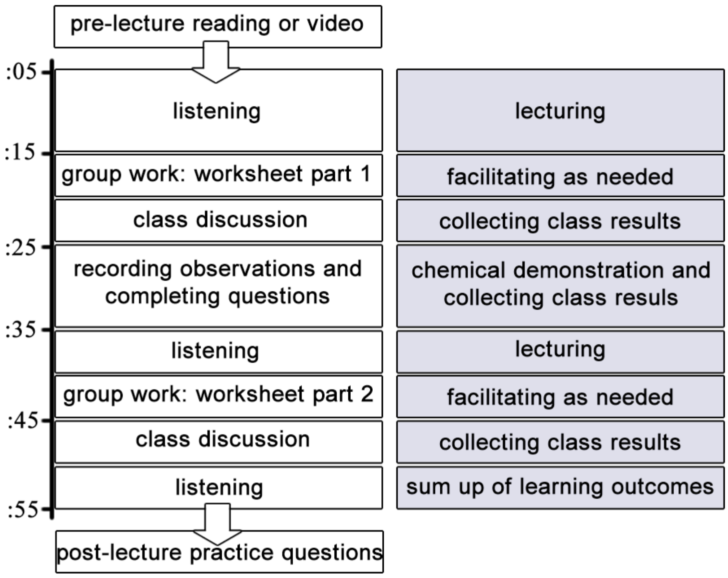

Figure 1: Lecture plan for Chemistry lecture showing an approximate timeline (in minutes) and student (left) and lecturer (right) activities.

125 demonstrations have been authorised for use in lectures at the School of Chemistry at the University of Sydney A technician is employed to prepare these and to clear away after the lecture. Lecturers order their demonstrations through an online booking system requiring only that they are

ordered 2 days before the class. This system is designed and supported to make it as easy as possible for demonstrations to be performed. Nonetheless, there has been a notable decline in the number of demonstrations being ordered in recent years and some evidence of crowd-pleasing demonstrations being performed even when are not relevant to the theoretical material. Through the development of worksheets to enable ILDs to be easily performed, it is also hoped that this can be addressed.

ILDs were developed and carried out in the lecture component of the second semester "Fundamentals of Chemistry 1B" (CHEM1002) unit of study from weeks 8 to 13. Students take this unit of study from every faculty in the university and, typically, have not studied Chemistry at high school. Nonetheless, as the intervention was introduced in the final part of the year, all students would have experienced traditional chemistry demonstrations. Screen-captures videos of the lectures were provided to all students. Where possible, videos of the demonstrations captured in the class where also made available.

The design and evaluation of the ILD worksheets was carried out as part of a third year 'Talented Student Project'.

EVALUATION OF THE INTERACTIVE LECTURE DEMONSTRATIONS

Evaluation of the effectiveness of the ILDs commenced upon their introduction at the beginning of week 8. The effectiveness of the implemented worksheets was evaluated through surveys in weeks 9 (survey A) and week 13 (survey B) and passive observation of students over a number of lectures between week 8 and 13. Particular note was taken as to the current state of attention of the students during periods of traditional lecturing, during demonstrations and during the allocated periods to complete worksheets.

ILD WORKSHEET DEVELOPMENT

The ILD worksheets developed in this project were designed to accompany existing demonstrations in the development of ILDs. Initially, at least, these worksheets were loosely based on the 8-step interactive lecture demonstration procedure previously developed in Physics (Sokoloff & Thornton, 2004). However, it quickly became apparent that this procedure was not ideal for direct application to Chemistry, as our demonstrations typically last seconds rather than minutes and cannot easily be repeated. Furthermore, the primary focus of the physics-based ILDs is on prediction of measurements and calculations derived from the demonstration outcomes. While the overall format was useful, application to chemical education required a more flexible model that would suit the variety of chemical demonstrations available.

The modified ILD model for chemical education involved multiple components. These included a short introduction and overview of the ILD (shown in yellow in Figure 2) and aspects designed to engage the students in the demonstration (shown in green). The primary learning-based section (shown in blue) required students to answer questions related to both the ILD and the concept behind the ILD. Finally, an extrapolation element (shown in red) required the students to apply similar concepts to an alternative example or related assumed knowledge to the presented concept. Given the variety of content and demonstrations in chemistry, not all ILD worksheets incorporated every element of the adapted model. Factors influencing the construction of each worksheet often depended on time, the nature of the demonstration and the relevancy of the demonstration to the lecture content.

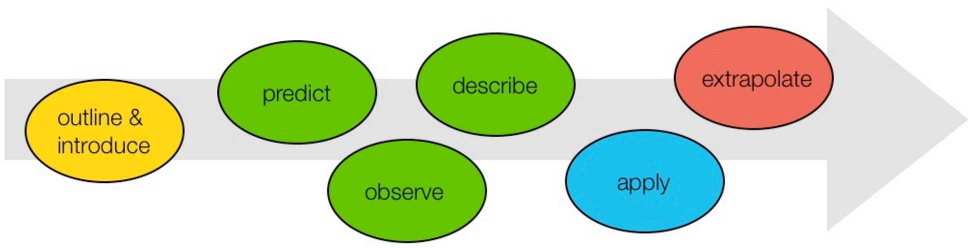

Figure 2: General design of the ILD worksheets.

The worksheets were designed for students to complete in a short amount of time. In any given lecture, a maximum time of about 10 minutes was allowed, including watching the demonstration itself. This was in keeping with the rotation of pedagogies over the duration of the lecture and staying within the limits of the students' ability to consistently pay attention (Bunce, Flens, & Neiles, 2010, Bligh, 2000). Four example worksheets are given in Appendix A. Particular focus was given to emphasising and cementing immediately learned content and drawing on relevant assumed knowledge not necessarily introduced in the current lecture. For example the ILD worksheet titled "Reaction of Sodium Hydroxide with Carbon Dioxide" (see Appendix A-4) presented a challenge question that linked the inorganic acid-base concepts with the organic chemistry-based material the students had been taught in the weeks prior to introduction of the ILDs.

Over the five weeks of observation, the students appeared to engage more with the content. When asked to complete the worksheets, the students were encouraged to discuss the questions with each other. By week 13, this part of the lecture had become routine. Lecture attendance was roughly constant from week 8 to 13 with around 50% of students present per lecture. Given the introduction of the innovation towards the end of the academic year, it was difficult to properly gauge fluctuations in attendance of the students and if the approach had any effect on attendance. Interestingly, there was a noticeable shift in seats occupied by students; the first three rows of the lecture theatre completely full by the end of week 13.

The short, anonymous and voluntary surveys comprised of 5 (survey A) and 6 (survey B) multiple choice questions (MCQs) and three open-ended questions. The multiple-choice questions provided five available responses on a standard Likert scale. The first survey was distributed immediately prior to the third lecture of week 9. The anonymous and voluntary nature of participation was emphasised, and the completed surveys were collected as a pile at the exits of the lecture theatre at the conclusion of the lecture. A total of five ILDs had been carried out at the time of the first survey.

Thirty-nine students chose to participate in the first survey, which was roughly half of the total number of students in attendance at that particular lecture. The results of the MCQ part of the survey suggested the students found the ILDs beneficial and engaging (Figure 3). The majority of students indicated their understanding of the connection between the ILDs and the course content.

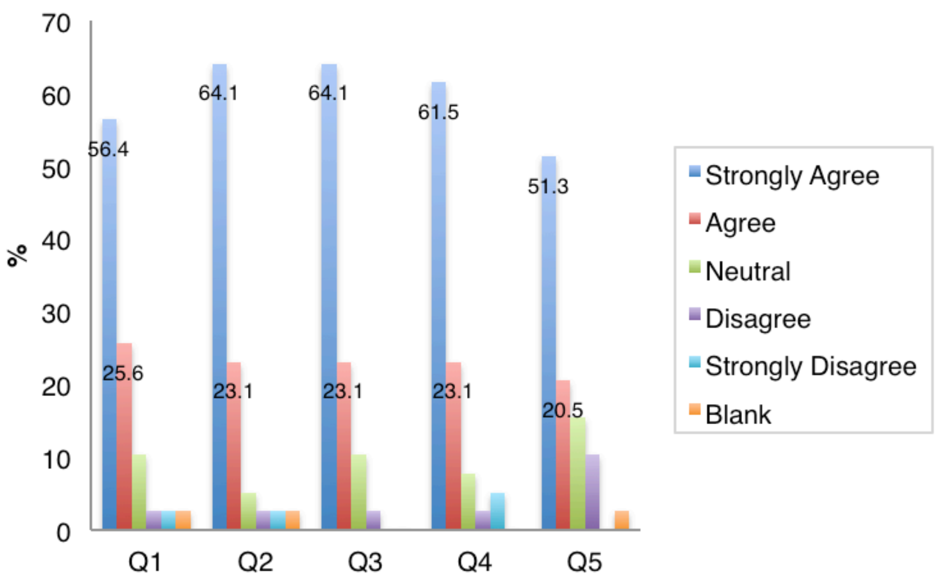

Figure 3: Student response to the MCQs of survey A (n = 39). Q1 The demonstration enhanced my learning experience; Q2 The link between the demonstration and the lecture context was clear; Q3 The worksheet aided my understanding of the chemical concepts illustrated; Q4 I generally enjoy demonstrations in chemistry lectures; Q5 Demonstrations increase my motivation for attending lectures.

The open-ended questions of the distributed surveys facilitated any student comments. Of the 39 students that completed surveys, 19 provided additional comments. A selection of these are listed in Table 1.

Table 1: Selection of the student comments received from the open-ended questions of survey A (distributed in week 9).

Question	Responses
What were the best and worst features of this demonstration?	"It was very engaging! It was good because it enabled us to see the physical aspects of the theory we learn" "Allows practical application to theory and supports what we have learnt." "Best -> Enjoyable & interesting, putting what we have learnt into practice for an easier understanding."
What were the best and worst features of this worksheet?	"Best -> it is progressive and builds upon itself. Worst -> Not heaps of info typed to go back to study." "Best: They helped to apply things being learned to gain understanding. They helped me focus." "Best -> the worksheets explain concepts very well and test my understanding. I'm also more likely to remember information if questions are completed while learning."
Do you have any other comments that you consider relevant?	"It would be a better course if this technique of teaching was used the whole way through the course. It draws for more attendance as the lectures are more interesting and allow us to get involved with what is being learnt than just listening and taking notes. Applies the practical to the theory." "You would have to be a real f****** idiot if you think the worksheets & demonstrations don't help. They are a fantastic idea, no sarcasm, even though it may look like it!" "I really like having worksheets to fill out because it makes the lectures interactive and enables me to gain a better understanding of the topic."

The comments received in the open-ended section of survey A further emphasised the positive effects of the ILDs. The majority of students indicated ILDs were beneficial, facilitated learning and improved motivation. In many responses, students provided comments preceded by the word "best," but did not provide any additional response under the label of "worst" or other negative terms.

The second survey (distributed in week 13) saw an increase in the number of students participating in the survey. The number increased from 39 (survey A) to 61 participants (survey B, Figure 4). Similar to the data collected from survey A, roughly half (n = 45) provided additional comments in response to the open-ended questions.

The students responded generally very positively to the worksheets. Again, the students indicated they understood the connection between the ILDs and the course material. Furthermore, positive responses helped to strengthen the links between practical application of learned content and students' motivation. The response to Q2 was the most noticeable in terms of varied response. This particular MCQ survey provided the students with an opportunity to compare the demonstrations without worksheets with ILDs. The results may be interpreted as the students' reiteration of the positive effects in terms of providing engagement, facilitating learning and increasing motivation via the coupling of worksheets with the demonstrations

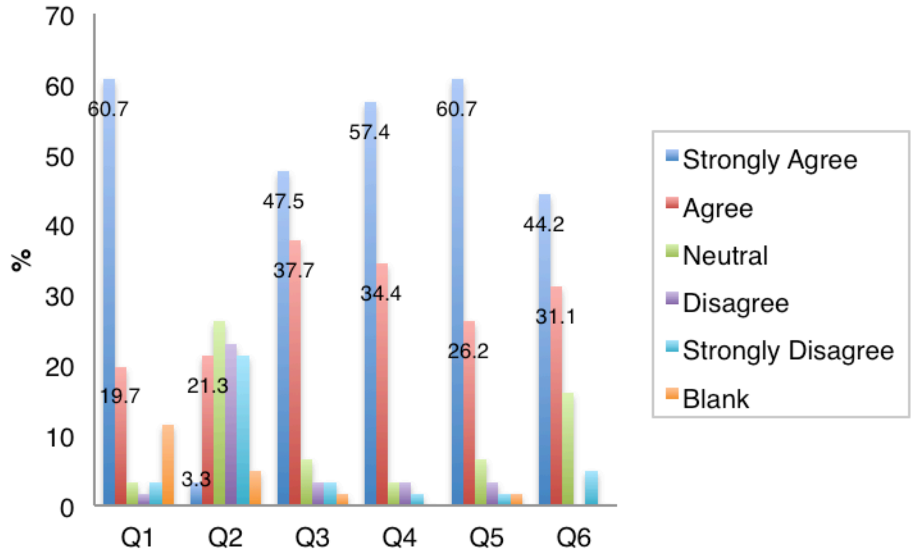

Figure 4: Student response to the MCQs of survey B (n = 61). Q1 The demonstrations with worksheets enhanced my learning experience; Q2 The demonstrations without worksheets enhanced my learning experience; Q3 The link between demonstrations with worksheets and the lecture context was clear; Q4 The demonstration worksheets aided my understanding of chemical concepts; Q5 I generally enjoy demonstrations in chemistry lectures; Q6 Demonstrations increase my motivation for attending lectures.

The feedback provided in response to the open-ended questions was largely positive (Table 2). The majority of students indicated the ILDs provided a necessary bridge between theoretical and practical learning in a lecture environment. Particularly for students with minimal experience with chemical concepts, the links between lectures and the practical application of this content is not always clear.

Table 2: Selection of the comments received from the open-ended questions of survey B (distributed in week 13).

Question	Responses
What were the best and worst features of this demonstration?	"Demonstrations turn the chemical jargon in lecture notes into tangible qualities & effects." "Good. Gives you an idea how things work visually, takes learning off the page." "Best were engaging diagrams and linking theory. Worst were the domes [demos] w/out relevant worksheets."
What were the best and worst features of the worksheets?	"Best: Allows learning throughout the lecture instead of blindly copying notes & not really absorbing anything. Why [Was] more motivated to come to lectures as a result, because I knew I would definitely learn something (still missed some though!). Worst: N/A." "Good at cementing knowledge. Stop you daydreaming. Identify problem areas straight away." "Going through real questions & concepts that challenged learning forced me to engage with the content."
Do you have any other comments that you consider relevant?	"…methods of teaching enhanced my learning significantly and encouraged me to come to every lecture." "I really liked this unit in chemistry, seeing reactions happen is good for visual learners." "It tests how well we understand the concepts."

CONCLUSIONS AND FUTURE WORK

The feedback received from the students suggested the interactive lecture format was highly effective in engaging the students, increasing their motivation for both attendance and for learning. This interactive learning format begins to address the gap between traditional lecturing and the practical application of the covered content. The direct application of the content appears to be more motivating for students than traditional methods with more distant benefits to the student.

As a pilot project in the area of Chemistry-based interactive lecture demonstrations, further development of teaching methods and collecting additional data on students' ability to learn is required, including the correlation of students' responses to the ILDs with their final marks. Ideally, more comprehensive surveys would be developed and distributed throughout the entire 13-week semester. Furthermore, the ILDs could be carried out over the entire semester. Quantitative statistical analyses of responses to repeat questions would give an idea of progress of the students participating in the ILDs. Additional quantification of student engagement through video recordings of students, use of clickers, or monitoring attendance anonymously would provide useful data. The development of the ILD pedagogy into an efficient tool could potentially lead to its widespread application throughout all undergraduate chemistry units.

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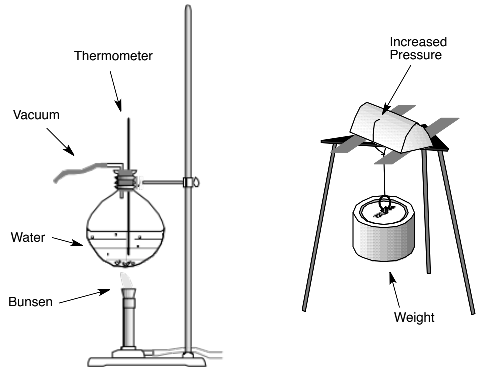
APPENDIX A-1

EFFECTS OF PRESSURE

In these demonstrations, the changes in the properties of water and carbon dioxide under increased and reduced pressure are illustrated. The setups for the demonstration under *reduced* pressure (left) and *increased* pressure (right) are illustrated below. Blocks of H_2O and CO_2 are subjected to increased pressure in the form of weighted wires.



1. What is the boiling point of water at atmospheric pressure?

2. What do you think will happen to the boiling point of water under *reduced* pressure?

   a. Increases b. Decreases c. Remains unchanged

3. Write down your observations of the boiling point of water under *reduced* pressure. At what temperature did the water boil?

4. What do you think will happen over time as the weighted wire sits on the ice block?

5. What happens to the melting point of H_2O under *increased* pressure?

   a. Increases b. Decreases c. Remains unchanged

6. What about the sublimation point of CO_2 under *increased* pressure?

   a. Increases b. Decreases c. Remains unchanged

Additional Question

1. What would happen to the boiling point of water if the pressure was *increased*?

APPENDIX A-2

HOW DO pH INDICATORS WORK?

pH indicators detect the presence of H^+ and OH^-. They do this by reacting with H^+ and OH^-: they are themselves weak acids and bases. If an indicator is a weak acid and is coloured and its conjugate base has a different colour, deprotonation causes a colour change.

The ratio of the concentration of the indicator, HInd, and its conjugate base, Ind^-, determines the colour we see. This ratio depends on the pK_a of the indicator and the pH according to the Henderson-Hasselbalch equation:

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{Ind}^-]}{[\mathrm{HInd}]}$$

Remember: $\log x < 0$ when $x < 1$,
$\log x = 0$ when $x = 1$ and
$\log x > 0$ when $x > 1$

1. If the pH of the solution is *equal* to the pK_a of the indicator, which of the following is true?

   (a) $[Ind^-] < [HInd]$ (b) $[Ind^-] = [HInd]$ (c) $[Ind^-] > [HInd]$

2. If the pH of the solution is *lower* than the pK_a of the indicator, which of the following is true?

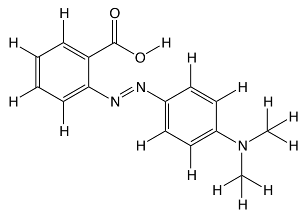
   (a) $[Ind^-] < [HInd]$ (b) $[Ind^-] = [HInd]$ (c) $[Ind^-] > [HInd]$

3. If the pH of the solution is *higher* than the pK_a of the indicator, which of the following is true?

   (a) $[Ind^-] < [HInd]$ (b) $[Ind^-] = [HInd]$ (c) $[Ind^-] > [HInd]$

4. If HInd and Ind^- are different colours, at about what pH do you expect the colour of an indicator solution to change?

5. The molecular structure of the indicator *methyl red* (pK_a of 5.1) is shown on the right. Circle the H atom that is *not* present in its conjugate base.



6. The deprotonated form of this indicator is yellow and the protonated form is red. What colour do you **expect** a solution to be when acid is added to a neutral solution containing the indicator? Add your prediction to the first cell in the table below.

7. Complete the table by adding your predictions and observations. In the final column, indicate the form of the indicator that is present (HInd or Ind^-)

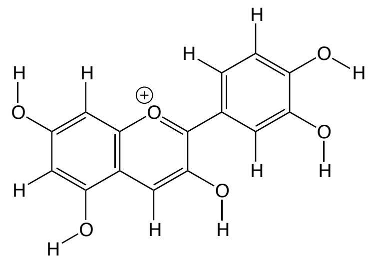
Solution	Prediction	Observation	Form present
Acidic solution containing methyl red			
Neutral solution containing methyl red			
Basic solution containing methyl red			

APPENDIX A-3

Indicators

NATURAL pH INDICATORS

The molecule in red cabbage responsible for its colour is an *anthocyanin*. Anthocyanins are a large group of plant pigments that occur in all higher plants including flowers and fruits. They are responsible for the colours of many of our foods, including blueberries to red wine. The structure of the anthocyanin present in red cabbage is shown on the right.



1. Circle one of the H atoms you expect not to be present in the deprotonated form of this anthocyanin.

2. Complete the table below by noting down the colour changes that occurred when acid and base are added to the solution containing the natural indicator.

Indicator	Acidic	Neutral	Basic
Red cabbage			
Red wine			
Tea			

3. Predict the colour of ‘red cabbage’ when it is grown in the following soils:

   (a) acidic soil (b) neutral soil (c) alkaline soil

4. Red cabbage turns a distasteful blue colour when cooked. What would you add to a saucepan of red cabbage so that it keeps its red colour?

5. Iced tea is often much paler in colour than traditional hot tea. What ingredient is added to cause this colour change?

Challenge Question

1. Why do we need indicators which change colours at pH values apart from 7.0?

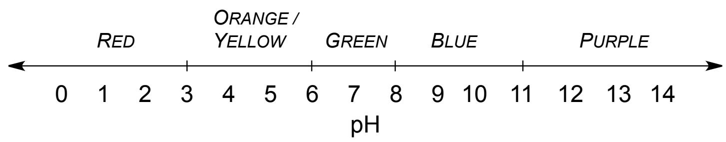
   Hints. Complete the chemical equation below. What is present when enough OH^- has been added to react with *all* of the carboxylic acid? What is the pH of a solution containing this?

   $CH_3COOH(aq) + OH^-(aq) \rightarrow$

APPENDIX A-4

REACTION OF SODIUM HYDROXIDE WITH CARBON DIOXIDE

In this demonstration, a carbon dioxide (in the form of “dry ice”) is added to a solution of sodium hydroxide and universal indicator. Any changes in pH that occur are observed by a change in colour of the universal indicator (chart below).



The equations for the dissolution of carbon dioxide into water is given below:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

1. Is carbon dioxide an acid, a base or neither?

2. What colour was the sodium hydroxide solution before the addition of dry ice?

3. Predict what will happen when the carbon dioxide is added to the sodium hydroxide solution.

4. Describe what did happen and change your answer to Q1 if required.

Challenge Questions

1. Write out the equations for the reactions of SO_2, SO_3, ClO_3 and MgO with water. Are they acids, bases or neither?

   $SO_2 + H_2O \rightarrow$

   $SO_3 + H_2O \rightarrow$

   $ClO_3 + H_2O \rightarrow$

   $MgO + H_2O \rightarrow$

2. Fill in the curly arrows for the reaction of water with carbon dioxide, described by equation X.